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Original Research Paper

Climate-Driven Phenological Mismatches Between Migratory Birds and Peak Insect Abundance

Dr. Anandbabu Rangasamy[1*], Nipun Setia[2], Aarsi Kumari[3], Hansaraj Pradhan[4],

Dr. Gargi Shekhar[5], Dr. Rahul M. Sonavale[6], Chitranjanprasad Sah[7]

[1]Assistant Professor, Community Medicine Aarupadai Veedu Medical College and Hospital, Vinayaka Mission's Research Foundation (DU), Salem, Tamil Nadu, India. Email: getanand09@gmail.com, ORCID: https://orcid.org/0000-0002-8897-6547*
[2]Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India. Email: nipun.setia.orp@chitkara.edu.in, ORCID: https://orcid.org/0009-0005-8635-6802
[3]Assitant Professor, Department of Computer Science and Information Technology, ARKA JAIN University, Jamshedpur, Jharkhand, India. Email: aarsi.k@arkajainuniversity.ac.in, ORCID: https://orcid.org/0009-0008-5355-234X
[4]Assistant Professor, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India. Email: hansarajpradhan@soa.ac.in, ORCID: https://orcid.org/0009-0000-6565-5823
[5]School of Agriculture, Dev Bhoomi Uttarakhand University, Uttarakhand, India. Email: dehradunagri.gargi@dbuu.ac.in, ORCID: https://orcid.org/0000-0001-9716-9010
[6]Krishna Institute of Science and Technology, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad, Maharashtra, India. Email: rahulsonavale777@gmail.com, ORCID: https://orcid.org/0000-0002-9844-1837
[7]Assistant Professor, Department of School of Engineering & Technology, Noida International University, Uttar Pradesh, India. Email: chitranjan.prasad@niu.edu.in, ORCID: https://orcid.org/0009-0005-0251-1482

Key Words

Climate change, Phenological mismatch, Migratory birds, Insect abundance, Reproductive success, Habitat conservation, Ecological disruption.

Abstract

Phenological mismatches between migratory birds and optimal insect abundance caused by climate change have become an important ecological issue as a result of global warming. The rising temperatures are causing insects to come out earlier in the season, and migratory birds are not adapting to this, causing a mismatch in the arrival of the birds and insect supply. Such a discrepancy influences reproductive success, chick survival, and stability in a long-term population. As an example, the Common Cuckoo and Eurasian Redstart species have experienced 7- and 5-7-day arrival delays that cause reduced reproductive success. The black-throated blue warbler has experienced a 10-day imbalance, and the effect has also been the same as far as breeding outcomes are concerned. The author discusses the processes of these phenological changes and their impact on the population of species, but focuses more on the changes in insect phenology and the patterns of bird migration due to climate change. The paper presents the increasing danger of climate change in terms of synchrony between insects and birds through a review of the current literature. Among the main mitigation measures, there are the restoration of the habitats, the constant observation of the birds and insects, and the specific measures, such as feeding stations and artificial nesting. These results have suggested that urgent steps should be taken to reduce such mismatches and rescue endangered species. Policy adjustments and long-term research are needed to enhance conservation measures and help address the ecological impacts of phenological discrepancies. It is high time to take urgent measures to make sure that the population of migratory birds does not disappear and can survive in the times of rapid climate change.

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Introduction

Phenological mismatches are the result of the mismatch of events in the life cycle, such as migration, reproduction, or flowering, between dependent species with changes in environmental fluctuations, such as temperature, precipitation, or seasonal changes. These processes are normally synchronized so that organisms are at the appropriate place and at the appropriate time so that they can have access to the required resources, such as the arrival of migratory birds to the breeding sites when insect abundance is at its highest, which is an important source of food to the chicks. But with the increase in temperatures all over the world and the shift in climatic patterns, these are getting more and more out of sync. This disturbance may cause harsh ecological implications, particularly for the species that depend on accurate timing, such as migratory birds and insects as their food (Renner & Zohner, 2018). These mismatches are on the increase, and the evidence is growing to show that climate change is accelerating these changes in time, which can have a detrimental impact on the survival of species and stability of ecologies. Such incompatibilities may cause decreased breeding success, lowering the reproductive rate and, in the extreme scenario, local extinction, interfering with the food webs and ecological processes dependent on coordinated interactions (Jones & Cresswell, 2010).

Living organisms such as migratory birds and insects are invaluable to the ecosystems. Birds play an ecological role of pollinators, seed disseminators, and predators, and insects are the main food of many birds, especially during their breeding periods. One can take the example of insects such as moths, beetles, and caterpillars, which are important sources of food to the chicks of birds. Insects, as well as migratory birds, are important in ensuring a diverse ecosystem as well as maintaining biodiversity and ecological balance of the food webs. These species are closely intertwined: birds need insects to feed, insects need plants to feed on, which are influenced by climate-based changes over time. The cascading consequences may be imminent when there is a disruption of phenology, which results in a reduction of insect populations, a lack of food among birds, and finally, the bird population (Jones & Cresswell, 2010). This has caused a dependency on the migratory birds and insects, which highlights the importance of researching the impacts of climate-induced changes in the phenology of these species. In case the mismatches get more advanced, they might lead to a disruption of ecosystem services that are invaluable to human society, including pollination, pests, and food security (Garretson et al., 2022).

The issue of climate change has become one of the most important factors that have changed the dates of biological phenomena, such as the emergence of insects and the arrival of migratory birds. Climatic changes in temperature, precipitation, and frequency of extreme weather conditions have led to a mismatch in the timing of the season of species with the seasonal environmental resources. Insects, a temperature-sensitive group, are tending to be seen emerging earlier in the season than usual,

and migratory birds, despite the warming temperatures, are not changing their patterns of migration at as fast a rate. This asynchrony might lead to the appearance of birds at a time when the insect food sources are past their maximum, and birds have difficulty feeding their offspring, which may lead to low levels of reproductive success and even decreases in populations (Donnelly et al., 2011). The effects of climate change can be felt in high-latitude areas, where the migratory birds are highly susceptible to the changes. Insects are also emerging earlier in these regions, and in certain regions, they are simply not available at all when the birds come (Kellermann & van Riper, 2015). It has been discovered that this mismatch is never a local issue but is being experienced in various ecosystems all over the world. The effects are getting more drastic, and species cannot change quickly enough due to the difference in the environment. The mismatches have been identified in studies as contributing to the decreases in bird populations, particularly those species where the timing of the abundance of insects is crucial to be able to reproduce successfully (Renner & Zohner, 2018). Along with the increased related questions about climate-induced phenological mismatch, other studies, like (Mustapha et al., 2017), focus on the modifying effect of climatic conditions on the adaptation patterns of different organisms, e.g., migratory birds and insects. On the same note, (Khyade et al., 2018) write about how such species as butterflies adapt to environmental changes, which can be used, in turn, to discuss how birds may respond in terms of the mismatched timing. Reginald, (2024) states that the establishment of climate-resilient habitats is the most important to help these species in the context of phenological mismatches.

Climate change and its effects on phenology pose a serious problem to conservation science because it jeopardizes the equilibrium of ecosystems and species that are reliant on them. Climate change is enhancing the lack of interaction by changing the timing of important ecological events, ultimately leading to species that depend on each other not interacting. These transformations not only jeopardize biodiversity but also the ecological labyrinths that are broader and are the life-sustaining processes on earth. In this paper, the shifts will be addressed, both in terms of the mechanism that leads to these mismatches and the long-term effects of such mismatches on protecting the survival of the species, as well as the contribution to the knowledge of climate change impacts on migratory birds and insects. It is also important to understand these changes so that they can devise effective conservation measures to address the negative effects of the phenological mismatches on these species and ecosystems caused by climate change.

Key Contribution

1. The paper analyzes the effects of climate change on the causes of phenological mismatches between migratory birds and the optimal insect abundance, and the ecological impacts on both the species and the ecosystem.
2. It examines the processes involved in these misalignments, and how climatic factors

such as temperature and precipitation are changing when creatures migrate and when insects hatch.

3. The paper also poses mitigation strategies, which are habitat conservation, monitoring, and interventions, in an attempt to synchronize the migration of birds with insect availability.

The article has been structured in a manner that attempts to provide an understanding of climate-induced phenological disjuncture's between migratory birds and optimum insect abundance, in the context of their ecological implications. The section I, aims to establish the term of phenological mismatches, which is how climate change is changing the timing of important life events of both insects and birds, and causing ecosystem disruptions. Section II explains the exact timing differences that are being found in migratory birds, with an emphasis on the breeding success and the reproduction rates. Section III addresses the effect of climate change on insect phenology, which only adds to the lack of synchronization between insect availability and bird migration. Section IV focuses on the subsequent effects on migratory birds, especially on their breeding success, foraging behavior, and long-term population dynamics. Section V presents important mitigation measures, including conservation of habitats, surveillance, and treatments, including feeding stations and artificial nesting. The paper ends by highlighting how the mismatches should be dealt with by further research and immediate conservation efforts in order to save these species in the warming climate in Section VI.

Phenological Mismatches in Migratory Birds

Phenological mismatches of migratory birds take place when the migration of birds no longer coincides with optimum insect abundance because of climate change. Migratory birds use environmental signals such as temperature and photoperiod to schedule their arrival at the breeding sites when insects are present. Climate changes, however, are resulting in the emergence of insects and delayed arrival of birds, with the resultant shortage of food to the chicks and reproductive failures. Such deaths are a major threat to birds and the stability of the ecosystem.

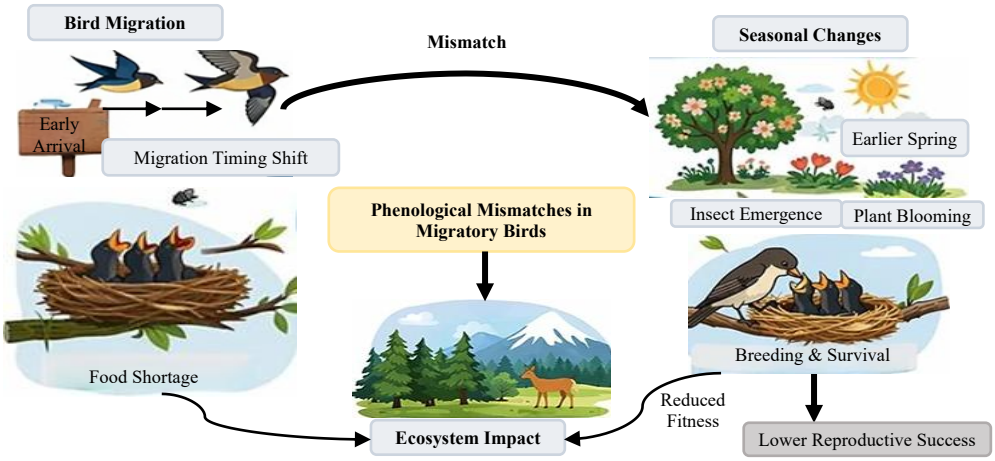

Figure 1: Phenological Mismatches in Migratory Birds

Figure 1 shows the effects of climatically induced phenological mismatches on migratory birds. It demonstrates that seasonal changes, like the growth of insects and the appearance of plants, are not linked to changes in the timing of migration, like the earlier arrival of migrants. The food shortages that result affect breeding and survival rates, creating decreased fitness and decreased reproductive success. The diagram highlights the chain reactions of these mismatches on the ecosystem.

Description of Typical Migration Patterns

Migratory birds have adapted to use the environmental cues, which include temperature and photoperiod (daylight duration), to predict the time to migrate. These signals assist the birds in timely arrival of breeding areas with the provision of the essential resources, particularly the food resources like insects, which are crucial in feeding the young. This synergizing plays a crucial role in the survival of the chicks since birds usually reach the breeding grounds when insects are at their best. An example of this is that most birds, including the common cuckoo (Cuculus canorus), synchronize their migration to be in northern Europe when caterpillar numbers are high, as this guarantees food security to their young ones (Burgess et al., 2018). The timing of the migration of the birds and the presence of the insects are critical in the effective rearing of chickens since insects supply the required protein needed to ensure the chick grows fast.

Recent research has, however, shown that these established migration patterns are also being affected as a result of climate change. Higher temperatures, particularly in the spring months, are changing the time of emergence and availability of insects. Other birds, in their reaction to the changing temperatures, have begun to begin or end their migration either earlier or later than typical, triggering a lack of synchronization with the insect cycle (Song et al., 2023). To illustrate this, when a bird comes sooner than normal, the insects that depend on it will not be in their most abundant state, and the bird will be without the food that it needs. On the other hand, when birds come late in time, there may not be many insects left, or they could have flown to seek a new habitat, hence food shortage. Such species as the common cuckoo, which rely on the right time when the insects emerge, are especially exposed to such change. These changes complicate the support of these birds to bring their own offspring to maturity, and the lack of time may eventually lead to low reproductive effectiveness or even to the loss of the population.

Discussion of How Changes in Climate are Affecting Migration Timing

Climate change, and specifically the increase in temperatures all over the world, has resulted in severe shifts in the timing of seasonal events such as the migrations of birds. During the evolution, migratory birds have evolved to perceive certain environmental signals, which are predominantly temperature and duration of the day, to know when to start their migration. The cues help to make sure that the birds reach their breeding grounds when food is available at its best, typically when the insect populations are the highest.

But with the increase in global temperatures as a result of climate change, these environmental cues are changing, and birds are currently experiencing problems in adjusting to these changes. A research article by (Mayor et al., 2017) showed that the time of spring green-up (when the leaves appear on the trees) has been observed to come earlier in recent years because of increased temperatures. The green-up takes place sooner, but the bird migration has not adapted at the same rate, and thus, studies have had a mismatch between the arrival of the birds and the availability of their food. As an example, in years where the trees fruit sooner (because of warmer weather), the birds might get to their breeding grounds only to discover that the insects they feed on are already at their life cycle stages. This causes food deficit among the birds, especially at the critical period of chick rearing age, when the birds are feeding their young ones.

This lack of synchrony between the bird arrival and food has severe implications for the bird population. Premature birds may get exposed to low temperatures and low food supply, whereas late arrivals may have problems in finding food to support themselves and their young ones. This shift in migration timings is a major challenge to the survival of migratory birds and might cause a decrease in population should such mismatches persist to rise in number and magnitude.

Examples of Specific Bird Species Experiencing Mismatches

A number of bird species have been found to suffer large mismatches in the synchronization of migration with the availability of insect prey. Indicatively, the Eurasian redstart (Phoenicurus) and the black-throated blue warbler (Setophaga caerulescens) have delayed arrival at the breeding grounds and have been out of synchronization with the abundance of insects, which chickens require as a food source (Kellermann & van Riper, 2015). These birds are dependent on the highest concentration of insects to supply enough food to their young, which develop fast and require a lot of food in the early stages of their growth.

The birds that come later, when the insect abundance is waning, have a problem accessing sufficient food to nourish their young ones. Consequently, this leads to reduced reproductive success, whereby fewer chicks are able to survive in adulthood. This is the lag in food supply in sensitive chick-rearing periods, which results in reduced survival of chicks and, eventually, the total population of these bird species (Stehelin & Schmiegelow, 2026). Time mismatch has been especially harmful to the species whose reproduction has a small window of success. These findings highlight the wider issue that phenological discrepancies are being witnessed in migratory birds worldwide and that the number of species affected by these effects is rising due to climate change.

With the escalation of climate change, there is a high chance that more species of birds will suffer the same disruption. The effects of such mismatches are not only limited to the individual species that have been affected, but also to the ecosystem in general. Birds are significant members of a given ecosystem since they

pollinate, control pests, and scatter seeds. The situation with the migratory birds with reduced numbers because of improper timing might have a ripple effect in the entire food web, leading to the eventual loss of biodiversity and the proper functioning of the ecosystem. These phenological gaps may be catastrophic to both the population of migratory birds and the ecosystems within which they live.

Phenological Mismatches in Peak Insect Abundance

Phenological mismatches of insect abundance arise when insects hatch into the environment earlier or later than normal with climate change, and this affects the timing of congruence between insect abundance and the migration of birds. Migratory birds rely on insects (particularly when rearing chicks) as they are a valuable source of nutritional benefits. An insect that will not hatch on time or that hatches too late can cause shortages of food to the young birds. This mismatch impacts reproductive success in birds and may also result in a reduction in the population of insects and birds.

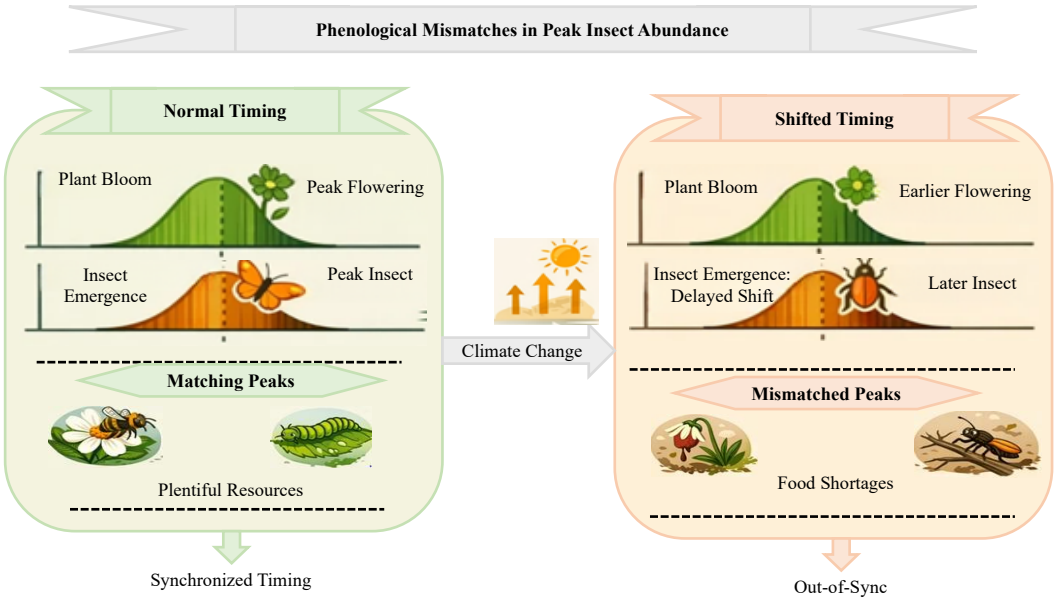

Figure 2: Phenological Mismatches in Peak Insect Abundance

Figure 2 shows the difference between normal and shifted timing of the peak abundance of the insects, which shows the impact of climate change. The left side depicts the time-dependent plant blooms and insect hatching, which yield resources. The Shifted Timing area on the right shows how climate change has resulted in the premature blooming of plants and the premature emergence of insects, with a mismatch in the timing of the plants and the insects. This time lag causes birds and insects to lack food, which highlights the problem of the ecosystem imbalance. The use of arrows and color palette highlights how these changes in phenology are caused by the impact of climate change.

Explanation of How Climate Change is Altering Insect Phenology

The insects are very sensitive to the levels of temperature, photoperiod, and rain. As the global temperatures increase because of climate change, insects are undergoing changes in their phenology, especially the timing of their life cycles. As an example, insects (such as moths and beetles) that migratory birds rely on as a crucial source of food are now hatching sooner in the spring due to higher temperatures (Sahoo et al., 2025). This premature development is due to the fact that insects are ectothermic organisms that also depend on the warmth of the environment to control their development, and the increase in temperature causes them to develop faster.

These changes in the insect phenology are destabilizing the natural coordination between insects and birds. Conventionally, birds would schedule their migrations to reach mating areas at the time of high insect population, as they would be assured of an easy source of food throughout the chick-rearing season. The earlier appearance of insects, however, creates a time lag between the appearance of insects and the arrival of migratory birds. Consequently, the birds are frequently either too late or too early to get to the optimal abundance of their major food sources, which worsens the phenomenon of phenological mismatch and reduces their reproduction (Sahoo et al., 2025).

Overview of Why Peak Insect Abundance is Important for Birds

The success of the reproduction of migratory birds largely depends on the presence of peak insect abundance. The insects, especially the larvae of insects, are a very significant food to the birds during the chick-rearing season, since they supply all the necessary nutrients like proteins and fats that the chicks need to grow and develop. Insects are also easy to digest and offer the required energy to the young birds to grow fast. The chicken will not survive without the proper availability of insects during this period, and the overall reproductive success of the bird would be hampered.

Temporal incongruencies in the occurrence of insects have far-reaching consequences on birds. With climate warming, insects will become available earlier, and birds might fail to take advantage of this maximum abundance because their migration does not match the insect availability. Early birds also risk the possibility of insufficient food, whereas late birds will have to deal with the fact that they might not find the insects at the right time after the life cycle has ended, and thus cannot find adequate food during the phase of rearing the chicks (Horton et al., 2020). This imbalance of timing causes nutritional deficiencies in the chicks, and this may lower their survival possibilities, ultimately influencing the population dynamics of migratory bird populations.

Discussion of Potential Consequences of Mismatches on Insect Populations

Insect phenology can also cascade down so that changes in climate cause changes in the insect populations. Early emergence of insects under the impact of warming might cause problems in locating appropriate sources of food. A large number of insects have depended on

particular plants as a food source in the early growth phase, and a lack of the required resources (e.g., because of changed plant phenology) can lead to bad insect development (or even death) (GangMa et al., 2024). In the same vein, anomalous patterns of emergence, in which insects occur in smaller or more dispersed form, may result in competition over resources, resulting in low survival and low population levels.

The lack of correspondence between the population of insects and insect food resources may also cause changes in the distribution of insect species. As an example, more resilient species, which can adjust to higher temperatures in older periods, can flourish, and more vulnerable species can decline or relocate. This process can also upset the food web, especially when it comes to migratory birds, which depend on particular species of insects to feed (Horton et al., 2020). Where there is an extreme reduction in the insect population, it increases the imbalance, thus providing the birds with minimal sources of food when they arrive. This has eventual effects on the reproduction success of birds and may lead to the reduction of populations, creating a negative feedback loop as the insect species and the bird species fail to stabilize their populations.

Impacts of Mismatches on Migratory Birds

Effects on Breeding Success and Reproductive Rates

Phenological incompatibilities may have a considerable effect on the breeding success and reproductive rates of migratory birds. The migratory birds are dependent on the availability of insects to feed the chicks in due time. Arrival of birds at their breeding grounds late means that they fail to catch the insects at their best, and the children are likely to have a poor food supply. This mismatch in the development of insects with the migration of birds causes the poor development of chicks, decreasing the survival rates and finally decreasing the reproductive success (Visser & Gienapp, 2019). Research has revealed that birds will fail to get the best of the insects, thereby reducing the chances of successful rearing of the chicks, since the chicks will not get the needed nutrition during the initial periods of growth.

With further occurrences of climate change, where insect populations shift their time patterns, this mismatch is bound to deteriorate, causing even more impact on reproductive success (Dineshkumar, 2025). The breeding success effect may cause a decline in the number of the populations in the long term, especially in species that are highly dependent on the coordination between migration and the availability of insects. This has been seen in other species where food supply has been delayed during periods of vital breeding, leading to decreased survival of fledlings and a reduction in the population in the long run.

Table 1: Timing Mismatches Between Migratory Birds and Insect Abundance: Effects on Reproductive Success and Population Dynamics

Species	Timing Mismatch (Days)	Impact on Reproductive Success	Observed Population Change
Common Cuckoo (Cuculus canorus)	7	Decreased chick survival rates due to misaligned insect timing	Declining population (reduced chick survival)
Eurasian Redstart (Phoenicurus)	5–7	Reduced fledgling success due to a mismatch with insect abundance	Population decline (fledgling survival issues)
Black-Throated Blue Warbler (Setophaga caerulescens)	10	Lower reproductive success, especially in regions with mismatched insect emergence	Declining in some regions (fledgling survival issues)

Table 1 addresses the research of (Kellermann & van Riper, 2015; Visser & Gienapp, 2019) about the mismatch of time in the migratory birds with the abundance of insects. It shows the main species that are influenced by the phenological changes, the timing disparity (in terms of days), the effect on reproductive success (decreased chick survival and fledgling success), and the change in population (reduced populations and problems with survival). The table highlights the contributions of these mismatches to the eventual reduction in populations of migratory birds to highlight the greater ecological effects of climate-related phenological disturbances.

Changes in Foraging Behavior and Food Availability

The mismatch of the timing of insects and birds' migration compels the birds to adjust their foraging habitats based on access to food. Migratory birds usually depend on insects, especially insect larvae, as a good source of energy and nutrients in the highly demanding chick-rearing phase. Lack of insects at the appropriate time can force the birds to increase their foraging site to find adequate food sources, or to feed on less favorable food sources, including seeds or fruit, that do not necessarily contain the nutrients needed to help the chicks develop (Martay et al., 2023). In other instances, birds might be left to forage in unfavorable conditions, resulting in low food levels and a lack of rapid growth of the chicks. Even though a foraging behavior can be adjusted by foraging longer or in other places, this does not make the best changes and can undermine the survival of the chick. This altered access to the best food adequate may adversely affect the capacity of the birds to produce healthy offspring, which, in the long run, will lead to the population depletion. These modifications in foraging behavior are indicative of the displacements in the ecosystem at large due to the phenological mismatches and

point to the significance of timing in the sustenance of healthy populations of migratory birds.

Potential Long-Term Consequences for Bird Populations

Phenological delays in the arrival of migratory birds in relation to optimal insect abundance may result in extreme reduction of bird populations. When birds do not match their migration with food availability, their breeding performance is affected thus lowering population growth, which in the long-term may cause population losses. The species that depend on the exact time to migrate and breed are particularly sensitive to these changes since they might not respond to the changes in the food supply fast enough. The absence of such synchronization in the long run may cause species to change their migration patterns, which may result in more ecological imbalance. Indicatively, the species can start to migrate sooner or later in order to align with new food sources, yet the new patterns of migration might create new problems, including exposure to high predation, or inability to find the appropriate habitat where they are going (Miller-Rushing et al., 2010). These alterations can also bring new ecological dynamics whereby certain species will thrive whereas others will become weak, which will further affect the stability of the ecosystem. Finally, there may be consequences of the mismatches in the long term that are measured in population fragmentation, lower genetic diversity, and the extinction of species that cannot adapt to the environment which is quickly evolving.

Mitigation Strategies for Climate-Driven Phenological Mismatches

Suggestions for Habitat Conservation and Restoration

Habitat conservation and restoration is one of the best plans to reduce the impact of climate-induced phenological mismatches. It could be beneficial to make and preserve climate-resilient habitats that would enable migratory birds as well as insects to adapt to new phenological patterns. The restoration of wetlands, grasslands, and forests as important ecosystems that support both birds and insects could be a subject of the restoration activity. An example of this is wetlands, which are important to most of the migratory birds in the period of stopover, which are good sources of food and a place to rest. Equally important is the forests and grasslands which help sustain the population of insects, especially insects that are used by the birds as food during the breeding period. Also, it is important to have the connectivity of these habitats with ecological corridors so that the movement of the species can be accomplished and to aid the migration of the birds and insects as climatic changes alter their habitat. The conservation and preservation of these habitats that prevent human development or degradation will help to reduce the consequences of climate-induced changes in phenology and the ability of species to adapt to the changing environment (Rushing et al., 2020).

Table 2: Habitat Conservation and Restoration Strategies for Mitigating Climate-Driven Phenological Mismatches

Habitat Type	Role in Mitigating Mismatches	Conservation Action
Wetlands	Critical stopover sites for migratory birds; supports insect populations	Restoration and protection of wetlands from development
Grasslands	Provide habitat for insects and feeding grounds for birds	Conservation and restoration of native grasslands
Forests	Support diverse insect populations; provide nesting sites for birds	Reforestation and protection of existing forests
Ecological Corridors	Allow for species movement and gene flow	Establishment of wildlife corridors to connect fragmented habitats

Table 2 summarizes the important habitat types and conservation interventions that can be taken to counteract the climate-induced phenological mismatches. Both (Rushing et al., 2020; Williams et al., 2021) stress the value of wetlands and grassland when it comes to sustaining migratory birds and insect preys and forests and ecological corridors when it comes to supporting the migration of different species and their adaptation to climate changes. The findings highlight the role of habitat restoration, conservation and connectivity in mitigating ecological issues due to the occurrence of phenological mismatches.

Importance of Monitoring Bird and Insect Populations

Both bird and insect population should be monitored continuously to have an insight into the current effects of climate change on such species. Monitoring enables the investigator to trace the changes in phenology, changes in population trends, and changes in population distribution over time. Conservationists will be able to understand the impact of climate change on such species by gathering correct and current information on the time of migration, breeding success, and the emergence of insects. The information would be critical in recognizing the species that are at the greatest risk because of phenological incongruities, and in determining the changes in migration and food supply in the future.

The scientists are also able to identify early warning of the mismatches between migratory birds and their insect food using long term monitoring programs and this enables timely intervention to halt or alleviate the impact. To illustrate, in case, with data on the arrival of given species of birds, they are found early or late in the season compared to the greatest abundance of insects, conservation measures can be modified to address these species. This may involve the restoration of habitats, setting of feeding stations, and other initiatives that can assist birds to locate food at vital times (Williams et al., 2021).

Table 3: Monitoring Strategies for Understanding and Mitigating Phenological Mismatches in Migratory Birds and Insects

Monitoring Aspect	Key Benefits	Conservation Action
Bird Migration Timing	Identifies mismatches in timing with food sources	Adjust migration patterns and conservation efforts to synchronize bird arrival with peak insect abundance
Insect Emergence Patterns	Tracks shifts in insect phenology	Predict food availability and adjust bird migration timing
Reproductive Success of Birds	Evaluates the impacts of mismatched timing on chick survival	Implement feeding stations or artificial nests for support during food scarcity
Population Trends of Birds & Insects	Provides insights into population health	Inform conservation decisions to prevent population declines

Table 3 is a summary of the monitoring strategies that are needed in understanding and reducing the effects of phenological match between migratory birds and insects. According to (Williams et al., 2021), it determines the most important factors of monitoring, including the time of bird migration, emergence of insects, and reproduction success. The table identifies the ways in which the monitoring activities would offer important information on the health of the species, the conservation activities, and the prediction of the migration and food supply changes. The strategies can reduce the impact of phenological mismatches and improve the resilience of bird and insect populations by taking conservation measures that include changing migration patterns, feeding stations, and habitat protection.

Potential Interventions to Help Mitigate Mismatches

Besides habitat restoration and surveillance, it is possible to employ specific interventions to aid the populations of birds during the seasons of food shortage due to phenological disturbances. The development of feeding stations is one of such interventions, and can assist migratory birds to obtain adequate nutrition in the case of unavailability of natural food sources such as insects. These stations may also offer extra food at strategic areas of migration or breeding, to enable the birds to have adequate energy to reproduce. Introductions of artificial nests or nest boxes are also another possible intervention since species might have delayed breeding because of food shortage. The effects of food shortages on reproductive success can be reduced by providing appropriate nesting locations.

It is also essential to protect and increase the population of insects by protecting and managing habitats to reduce the impact of phenological mismatching on birds. Many migratory birds rely on insects as their main source of food, and when insects are unhealthy, the survival of birds is also at stake. By paying attention to the preservation of the habitat, which hosts insect species, including wildflower meadows, forests, and wetlands, one will be able to secure the stable supply of food to migratory birds during breeding season (Horton et al., 2020).

Table 4: Interventions to Mitigate Climate-Driven Phenological Mismatches Based on Conservation Strategies

Intervention	Purpose	Implementation
Feeding Stations	Provide supplemental food during migration or breeding	Set up bird-friendly stations with appropriate food types
Artificial Nests/Nest Boxes	Support breeding success in the face of food shortages	Install boxes for birds like warblers and redstarts
Habitat Protection for Insects	Ensure a stable food supply for birds	Protect and restore habitats like wetlands, meadows, and forests
Insect Habitat Management	Enhance insect populations and their availability	Create insect-friendly environments in restored habitats

Table 4 highlights the important interventions that will help to reduce the effects of the climate-related phenological mismatch between migratory birds and insects. Its interventions are aimed at increasing the food supply to birds (feeding stations and artificial nest, etc.), the control, and the management of insect habitats. The rationale and application of all the interventions rely on the conclusion of (Horton et al., 2020; Williams et al., 2021; Rushing et al., 2020) which explain the necessity to preserve insect populations, track the species and rehabilitate habitats to reduce the impact of mismatches that may occur due to climate change.

Conclusion

The effect of climate change has become a major ecological problem that has exposed migrating birds to phenological disjunctions relative to the favorable occurrence of insects. Birds have been known to depend on the relationship of their migration pattern to the optimal availability of the insects in order to guarantee their successful breeding. But the warming climate has been the cause of changes in the emergence of the insects, and this has resulted in a mismatch between the birds' migration pattern and the insect emergence. This disjunction has been found to cause reduced reproductive success, reduced chick survival, and long-term declines in population as seen in species such as the Common Cuckoo (Cuculus canorous), Eurasian Redstart (Phoenicurus), and Black-Throated Blue Warbler (Setophaga caerulescens). Mitigations of these mismatches include the conservation of the habitats, constant tracking of the migration patterns of the species, and timely interventions, which include feeding stations and restoration of the habitats. Further studies are needed to enhance the knowledge on the processes that cause the occurrence of phenological mismatches and their long-term impacts on migratory birds. More longitudinal studies are required to monitor the timing of migrations and food supply through multiple seasons to determine the accumulating effects of the mismatches. Also, studies of how species adapt in order to change their pattern of migration and the impact of habitat connectivity in assisting

species to cope with climate change would be instrumental. To better monitor changes in phenology and anticipate possible discrepancies before they cause serious impacts on populations, more systems at the global level need to be put into place. Phenological mismatches caused by climate changes cannot be solved through a one-sided intervention as it has to be multi-dimensional and involve immediate interventions and long-term conservation measures. Some of the urgent measures should involve restoration of vital habitats including wetlands, grasslands and forests and establishment of ecological corridors to help in ensuring connectivity of the migrating species. Furthermore, specific control over the breeds of insects, as well as feeding stations and artificial nests, will contribute to assisting the species at the time of insufficient supplies. The significance of keeping track of the bird and insect numbers cannot be overestimated, since such information will be used in the future conservation strategies. To address these mismatches and to have resilience of the ecosystems with regard to climatic changes it is necessary to put policy action and resource allocation first.

References

[1] Burgess, Malcolm D., Ken W. Smith, Karl L. Evans, Dave Leech, James W. Pearce-Higgins, Claire J. Branston, Kevin Briggs et al. "Tritrophic phenological match–mismatch in space and time." *Nature Ecology & Evolution* 2, no. 6 (2018): 970-975. https://doi.org/10.1038/s41559-018-0543-1

[2] Dineshkumar, P. "Integrating Genomic and Phenotypic Indicators to Improve Reproductive Efficiency in Sustainable Livestock Systems." *National Journal of Animal Health and Sustainable Livestock* 3, no. 2 (2025): 8-15.

[3] Donnelly, Alison, Amelia Caffarra, and Bridget F. O'Neill. "A review of climate-driven mismatches between interdependent phenophases in terrestrial and aquatic ecosystems." *International Journal of Biometeorology* 55, no. 6 (2011): 805-817. https://doi.org/10.1007/s00484-011-0426-5

[4] GangMa, Chun-Sen Ma, and C. L. Baaren. "Effects of climate change on insect phenology." *Effects of Climate Change on Insects: Physiological, Evolutionary, and Ecological Responses; Oxford University Press: Oxford, UK* (2024): 89.

[5] Garretson, Alexis, Natalie Feldsine, Megan Napoli, Elizabeth C. Long, and Rebecca E. Forkner. "Networks of Phenological Synchrony Reveal a Highly Interconnected Ecosystem and Potential Vulnerability to Climate-Driven Mismatches." *bioRxiv* (2022): 2022-07. https://doi.org/10.1101/2022.07.11.499341

[6] Horton, Kyle G., Frank A. La Sorte, Daniel Sheldon, Tsung-Yu Lin, Kevin Winner, Garrett Bernstein, Subhransu Maji, Wesley M. Hochachka, and Andrew Farnsworth. "Phenology of nocturnal avian migration has shifted at the

continental scale." *Nature climate change* 10, no. 1 (2020): 63-68. https://doi.org/10.1038/s41558-019-0648-9

[7] Jones, Tim, and Will Cresswell. "The phenology mismatch hypothesis: are declines of migrant birds linked to uneven global climate change?." *Journal of animal ecology* 79, no. 1 (2010): 98-108. https://doi.org/10.1111/j.1365-2656.2009.01610.x

[8] Kellermann, Jherime L., and Charles van Riper III. "Detecting mismatches of bird migration stopover and tree phenology in response to changing climate." *Oecologia* 178, no. 4 (2015): 1227-1238. https://doi.org/10.1007/s00442-015-3293-7

[9] Khyade, Vitthalrao Bhimasha, Priti Madhukar Gaikwad, and Pranita Rajendra Vare. "Explanation of Nymphalidae butterflies." *International Academic Journal of Science and Engineering* 5, no. 4 (2018): 24-47. https://doi.org/10.9756/IAJSE/V5I1/1810029

[10] Martay, Blaise, David I. Leech, Chris R. Shortall, James R. Bell, Stephen J. Thackeray, Deborah L. Hemming, and James W. Pearce-Higgins. "Aerial insect biomass, but not phenological mismatch, is associated with chick survival of an insectivorous bird." *Ibis* 165, no. 3 (2023): 790-807. https://doi.org/10.1111/ibi.13190

[11] Mayor, Stephen J., Robert P. Guralnick, Morgan W. Tingley, Javier Otegui, John C. Withey, Sarah C. Elmendorf, Margaret E. Andrew, Stefan Leyk, Ian S. Pearse, and David C. Schneider. "Increasing phenological asynchrony between spring green-up and arrival of migratory birds." *Scientific reports* 7, no. 1 (2017): 1902. https://doi.org/10.1038/s41598-017-02045-z

[12] Miller-Rushing, Abraham J., Toke Thomas Høye, David W. Inouye, and Eric Post. "The effects of phenological mismatches on demography." *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, no. 1555 (2010): 3177-3186. https://doi.org/10.1098/rstb.2010.0148

[13] Mustapha, S. B., A. Alkali, B. A. Zongoma, and D. Mohammed. "Effects of climatic factors on preference for climate change adaptation strategies among food crop farmers in Borno State, Nigeria." *International Academic Journal of Innovative Research*, 4, no. 1 (2017): 52–60.

[14] Reginald, P. Joshua. "Evaluating Climate-Resilient Agroecosystems Through Soil Health, Water Efficiency, and Biodiversity Indicators." *Journal of Environmental Sustainability, Climate Resilience, and Agro-Ecosystems* (2024): 1-7.

[15] Renner, Susanne S., and Constantin M. Zohner. "Climate change and phenological mismatch in trophic interactions among plants, insects, and vertebrates." *Annual review of ecology, evolution, and systematics* 49, no. 1 (2018): 165-182.

https://doi.org/10.1146/annurev-ecolsys-110617-062535

[16] Rushing, Clark S., Madeleine Rubenstein, James E. Lyons, and Michael C. Runge. "Using value of information to prioritize research needs for migratory bird management under climate change: a case study using federal land acquisition in the United States." *Biological Reviews* 95, no. 4 (2020): 1109-1130. https://doi.org/10.1111/brv.12602

[17] Sahoo, Swagatika, S. Dash, and P. Pradhan. "Phenological Shifts in Insect Life Cycles Due to Climate Variability." In *Book Title*, pp. 83-106. 2025.

[18] Song, Yiluan, Stephan B. Munch, and Kai Zhu. "Prediction-based approach for quantifying phenological mismatch across landscapes under climate change." *Landscape Ecology* 38, no. 3 (2023): 821-845. https://doi.org/10.1007/s10980-023-01595-0

[19] Stehelin, Tara E., and Fiona KA Schmiegelow. "Fledging success peaks later than insect prey biomass in two aerial insectivores: Evaluating potential phenological mismatch and fitness consequences." *Ornithology* 143, no. 1 (2026): 1-15. https://doi.org/10.1093/ornithology/ukaf061

[20] Visser, Marcel E., and Phillip Gienapp. "Evolutionary and demographic consequences of phenological mismatches." *Nature ecology & evolution* 3, no. 6 (2019): 879-885. https://doi.org/10.1038/s41559-019-0880-8

[21] Williams, John W., Alejandro Ordonez, and Jens-Christian Svenning. "A unifying framework for studying and managing climate-driven rates of ecological change." *Nature Ecology & Evolution* 5, no. 1 (2021): 17-26. https://doi.org/10.1038/s41559-020-01344-5